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Application of the Continuous Commissioning® Process at a K-12 School District Located In Central Texas

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ABSTRACT

The Energy Systems Laboratory (ESL) at the Texas A&M Engineering Experiment Station has successfully applied the Continuous Commissioning® (CC®) process at twenty (20) schools (14 elementary, 3 middle, and 3 high schools) and two (2) service buildings in the Austin Independent School District (AISD), over a seven (7) year period from 2005 to 2012 covering over 2.3 million square feet of conditioned space. Measures were implemented and tuned to accommodate specific existing conditions or HVAC configurations with the goal of improving comfort while reducing overall energy costs. These energy reduction measures contributed to 16% savings in electricity and 37% savings in natural gas consumption. The energy savings amount to a total cost savings of $650,997 ($0.27/sq.ft.) per year, which is 18% of the total energy costs. This study summarizes the problems identified and solved through the CC® process, and energy consumption savings achieved in the facilities. The paper also discusses lessons learned regarding effective selection and implementation of corrective and optimization measures across the district, along with the future direction of the CC® process as a key component in the overall energy management strategy for the school district.

INTRODUCTION

The Energy Systems Laboratory (ESL) at the Texas A&M Engineering Experiment Station (TEES) successfully implemented the Continuous Commissioning[1]® (CC®) process at twenty (20) schools and two (2) service buildings at Austin Independent School District (AISD), located in Central Texas over a seven year period from 2005 to 2012. This paper provides a description of the facility selection methodology, most common observations of energy usage in these facilities, energy savings analysis, and lessons learned from the implementation of the CC® process.

To assess the energy usage and building performance of these facilities, the ESL applied IPMVP Option C (IPMVP 2012), whole-building energy consumption analysis. The ESL staff investigated the facilities, identified issues associated with equipment and building automation systems, and provided solutions and future recommendations for energy efficiency in these buildings. An overview of the facilities commissioned is provided in Table 1. This paper focuses on the savings accumulated at each facility for a one year period following implementation. The savings calculations are provided in the savings analysis section.

OPPORTUNITY ASSESSMENT METHODOLOGY

High energy consumption, comfort problems, and availability (no major renovations scheduled, other factors that would inhibit reasonable allocation of performance improvement to the CC process) were key factors in the selection process. Ultimately, building selection was a cooperative process between ESL engineers and AISD facilities management staff.

Assessment of each individual facility was also a cooperative process requiring a team approach to identify the problems as well as a solution set acceptable to the facility and the district. The problems identified in the facilities are separated in two categories: Water-side systems and Air-side systems. In general, Water-side systems include chillers, boilers, cooling towers and other auxiliary equipment associated with water supply to the

[1] Continuous Commissioning® and CC® are Registered Trademarks of the Texas A&M Engineering Experiment Station, a member of the Texas A&M University System, an agency of the State of Texas.

distributed HVAC systems. Air-side systems generally include various types of air handling units (AHUs), fan coil units (FCUs), terminal boxes, and other ventilation equipment. Solving key problems with these systems contributed to improved occupant comfort and decreased energy consumption in the facilities.

Table 1. CC® Facilities List

Schools	Gross Area (Sq. Ft)	Implementation Year	Concurrent Enrollment
Elementary Schools			
Baranoff ES	69,322	2007-08	788
Blazier ES	82,850	2010-11	775
Casey ES	80,300	2007-08	754
Clayton ES	91,960	2009-10	974
Cowan ES	69,900	2007-08	649
Galindo ES	78,243	2005	771
Hart ES	69,610	2007-08	803
McBee ES	70,200	2007-08	704
Mills ES	69,610	2007-08	974
Overton ES	83,365	2009-10	715
Perez ES	78,000	2010	886
Pickle ES	116,000	2005	638
Rodriguez ES	69,342	2007-08	946
Sunset Valley ES	58,063	2008-09	448
Middle Schools			
Burnet MS	130,797	2009	969
Paredes MS	137,127	2007	1,067
Small MS	154,680	2007-08	1,167
High Schools			
Akins HS	262,742	2005-06	2,389
Anderson HS	265,180	2011-12	2,089
Reagan HS	252,842	2011	1,024
Auxiliary Service Buildings			
Clifton Center	35,198	2011-12	NA
Delco Center	35,571	2008	NA

KEY OBSERVATIONS OF THE WATER SIDE SYSTEMS

Night Time Operation of Chilled Water System

The Chilled Water System (CHWS) operates during night-time and unoccupied periods due to the following reasons:

- AHUs and FCU night-time temperature and relative humidity settings are not properly established to prevent the CHWS plant from starting unnecessarily.
- Occupants using the building during night-time turn on an override switch, which enables the chiller operation for the whole facility.

Simultaneous Operation of the Lead/Lag Chillers Under Low Load and Frequent Short-cycling of the Lag Chiller

- The lag chiller or chillers are operating when the demand for cooling did not require it to operate. When the building demand is small enough to be met by the lead chiller, the lag chiller is staged on either due to a reset based on the Outside Air Temperature (OAT) or other independent variable based on the control sequence set-up of a particular chiller system resulting in staging that does not match the actual building cooling load.
- Another frequent problem found in the facilities is the short-cycling of the lag chillers, turning on and off as the load, or load indicating process variable such as differential pressure or temperature fluctuate in a very short period of time. This problem causes the entire building cooling system to remain in a state of flux and significantly impacts comfort and increases energy consumption.

Hot Water System (HWS) Operation During Night-time and Summer Periods

HWS in many facilities are operating during night-time and unoccupied periods due to:

- Night-time temperature and relative humidity settings are not properly established to prevent AHU's, FCU's and the HWS plant from starting unnecessarily.
- Occupants in the building during night-time turn on an override switch, which enables the hot water system operation for the whole facility.
- The boilers are operating during summer-time even when the building staff suggested they didn't require heating. In many cases, boiler system lockout setpoints are set higher than required. Both conditions add an extra cost to the overall facility operation by allowing simultaneous heating and cooling due to leaky valves or other erroneous operation.

Constant Differential Pressure (DP) and Supply Temperature Setpoints

CHWS and HWS at various facilities are operating at a constant differential pressure (DP) setpoint, and constant supply temperature setpoint. In many cases, the DP set point is higher than necessary even for design conditions. The CHWS and HWS supply temperatures and loop DP can be modulated based on the building demand and/or the OAT. Equipment operation at constant supply temperature and constant DP leads to excessive energy usage and creates comfort issues for the occupants when spaces are overheated or overcooled as a result of valve blow-by.

Cooling Tower Constant Setpoint and Sub-optimal Lead/Lag Sequence

- The cooling towers maintain a constant setpoint of 85°F (typical design for the region) year-round without taking advantage of lower wet-bulb temperatures and lower loads during off-design conditions to provide cooler condenser water temperatures and improve chiller efficiency, even though the chiller may require lower condenser water temperatures (referred to in chiller operating manuals as "condenser relief") to achieve the published part-load efficiency rating.

- The cooling tower fan exhibits frequent on and off operations during short periods of time (fan short-cycling). This usually occurs during periods of low load and low ambient wet-bulb temperature and having more than one fan running when the weather conditions only require one. This results in expending more fan energy than necessary to achieve desired water temperature and potentially large temperature swings to the chiller.

KEY OBSERVATIONS OF THE AIR SIDE SYSTEMS

AHUs in various facilities were found to have multiple operation issues that added significantly to the overall energy usage. Observed major problems are shown below:

AHU Operation During Evenings/Night-time

Due to constant setpoints for both occupied and unoccupied periods, AHUs run at night even when the served area is unoccupied. With no setback for setpoints, AHUs are forced to run even when there is no requirement to maintain the space temperature and/or space relative humidity (RH).

AHU Operating with Constant Supply Air Temperature (SAT) and Constant Static Pressure (SP)

AHUs are operating at design SAT and SP setpoints all year long. There are no resets for increasing or decreasing SAT or SP based on the space demand. The constant setpoints can result in excessive cooling, heating, and airflow; and create comfort issues for the occupants.

AHU Operating with Simultaneous Cooling and Heating

Simultaneous cooling and heating are used to meet the supply temperature setpoint. This is frequently due to a preheat setpoint that is greater than the cooling coil leaving air temperature (CCLAT) setpoint (for example: 55°F PHLAT set point and 52F CCLAT set point). Therefore, when outside air temperature is below the preheat setpoint (for example: 50°F), the system unnecessarily heats incoming outside air before mixing with return air prior to entering the cooling coil. Simultaneous cooling and heating also frequently occur at the terminal box when re-heat is used to maintain space temperature under the influence of an unnecessarily low relative humidity set point or RH sensor that is out of calibration and reading a higher RH than actual RH in the space.

Excessive Outside Air Intake and High Minimum Air Flow Setpoints

- The AHUs supply outside air higher than the minimum established by the ASHRAE 62.1 (ASHRAE 2010) standard. The excessive outside air intake leads to more cooling and/or heating energy consumption to meet the space ventilation demand. Also, during humid days excessive OA intake leads to simultaneous cooling and heating because the air first needs to be cooled down, and then heated up to maintain space comfort.
- The cooling minimum flow setpoints for the Air-side systems (VAVs, AHUs, and FCUs) are set at a higher value than required. This leads to increased demand for reheat by prohibiting the terminal device from restricting cold primary air from the AHU in response to decreased cooling load, and adds more to the overall energy consumption (fan power, pumping power, chiller power, etc.). In a situation when reheat is not available and AHUs supply air through the VAV boxes, it creates comfort problems due to overcooling.

These problems were resolved by the CC® engineers and AISD staff members, and system performance was monitored during the Post-CC® period. The energy consumption, before and after implementing the CC® process at these facilities, was monitored and the savings information is covered in the following section.

PRE-CC® AND POST-CC® ENERGY CONSUMPTION DATA ANALYSIS

The CC® implementation process applied to the AISD facilities led to improved comfort and significant energy savings. The electricity and natural gas savings are calculated through the following steps:

1. Energy consumption baseline models are developed using energy consumption data regressed against the outside air dry-bulb

temperature during the selected baseline period. The utility data is provided by AISD. The baseline model can be a mean model, simple linear regression model, or a multi-parameter change point linear regression model.

2. Using the baseline model(s) from step 1, above, the energy consumption if no CC occurs for the Post CC period is calculated; this is the Baseline consumption.
3. The difference between the Baseline consumption and the Measured consumption for the period of one year after the CC® implementation (Post CC period) is the Savings.

The consumption and cost savings determined by this methodology are provided in Table 2. The cost savings are calculated based on the average rate of 22 AISD facilities during the year of 2012. The average rates are \$0.0932 / kWh for electricity and \$0.78 / CCF for natural gas. At these rates, the estimated cost savings is \$525,660 on electricity and \$125,337 on natural gas, for a total of \$650,997 or \$0.27 /sq.ft. for all the facilities combined. Figure 1 shows the breakdown of electricity and natural gas cost savings for each facility.

The comparison of weather normalized baseline to actual consumption and energy savings per square foot is shown in Table 3, which shows the reduction of 2.4 kWh /sq.ft on electricity, 0.07 CCF /sq.ft. on natural gas and overall EUI reduction of 15.2 kBtu/sq.ft. Figure 2, provides a comparison of the combined baseline and actual consumption per square foot for all 22 CC® facilities. Based on the Pre-CC® and Post-CC® energy consumption analysis, the implementation of performance improvement measures shows the estimated savings of 16% on electricity and 37% on natural gas consumption for all 22 facilities combined.

Table 2. Energy Savings during first year following implementation

Facilities	Gross Area (sq.ft.)	Electricity Savings (KWh)	Electricity Savings (%)	Electricity Cost Savings[1]	Natural Gas Savings (CCF)	NG Savings (%)	NG Cost Savings[1]	Total Cost Savings[1]
Elementary Schools								
Baranoff ES	69,322	141,112	14.2%	\$13,152	502	70.0%	\$391	\$13,543
Blazier ES	82,850	127,240	12.5%	\$11,859	4,264	44.8%	\$3,326	\$15,185
Casey ES	80,300	97,542	10.8%	\$9,091	322	56.1%	\$251	\$9,342
Clayton ES	91,960	337,490	21.1%	\$31,454	2,236	30.2%	\$1,744	\$33,198
Cowan ES	69,900	139,791	13.5%	\$13,029	1,200	41.7%	\$936	\$13,965
Galindo ES	78,243	183,856	13.1%	\$17,135	15,333	43.5%	\$11,960	\$29,095
Hart ES	69,610	92,601	10.6%	\$8,630	-536	-348.7%	-\$418	\$8,212
McBee ES	70,200	69,201	7.7%	\$6,450	-597	-39.2%	-\$466	\$5,984
Mills ES	69,610	143,043	14.5%	\$13,332	188	57.0%	\$146	\$13,478
Overton ES	83,365	285,927	22.2%	\$26,648	7,986	55.0%	\$6,229	\$32,877
Perez ES	78,000	122,389	8.3%	\$11,407	1,706	15.8%	\$1,331	\$12,737
Pickle ES	116,000	136,835	9.8%	\$12,753	7,150	34.3%	\$5,577	\$18,330
Rodriguez ES	69,342	82,796	9.0%	\$7,717	-693	-41.5%	-\$541	\$7,176
Sunset Valley ES	58,063	160,156	16.4%	\$14,927	7,615	49.8%	\$5,940	\$20,866
Middle Schools								
Burnet MS	130,797	461,097	20.1%	\$42,974	11,555	22.6%	\$9,013	\$51,987
Paredes MS	137,127	123,507	7.3%	\$11,511	204	18.6%	\$159	\$11,670
Small MS[2]	154,680	487,028	22.9%	\$45,391	NA	-	#VALUE!	\$45,391
High Schools								
Akins HS	262,742	558,843	12.6%	\$52,084	20,262	33.1%	\$15,804	\$67,889
Anderson HS	265,180	813,952	17.7%	\$75,860	19,630	32.8%	\$15,311	\$91,172
Reagan HS	252,842	321,545	9.5%	\$29,968	27,161	35.9%	\$21,186	\$51,154
Auxilliary Service Buildings								
Clifton Center	35,198	96,761	20.0%	\$9,018	5,079	22.7%	\$3,962	\$12,980
Delco Center	35,571	657,420	45.4%	\$61,272	30,122	77.5%	\$23,495	\$84,767
Total	**2,360,902**	**5,640,132**	**16%**	**\$525,660**	**160,688**	**37%**	**\$125,337**	**\$650,997**

[1]Cost savings are calculated based on average 2012 rate for the facilities where CC®was implemented
[2]For Small Middle School, natural gas data were not reliable due to changes in metering procedures

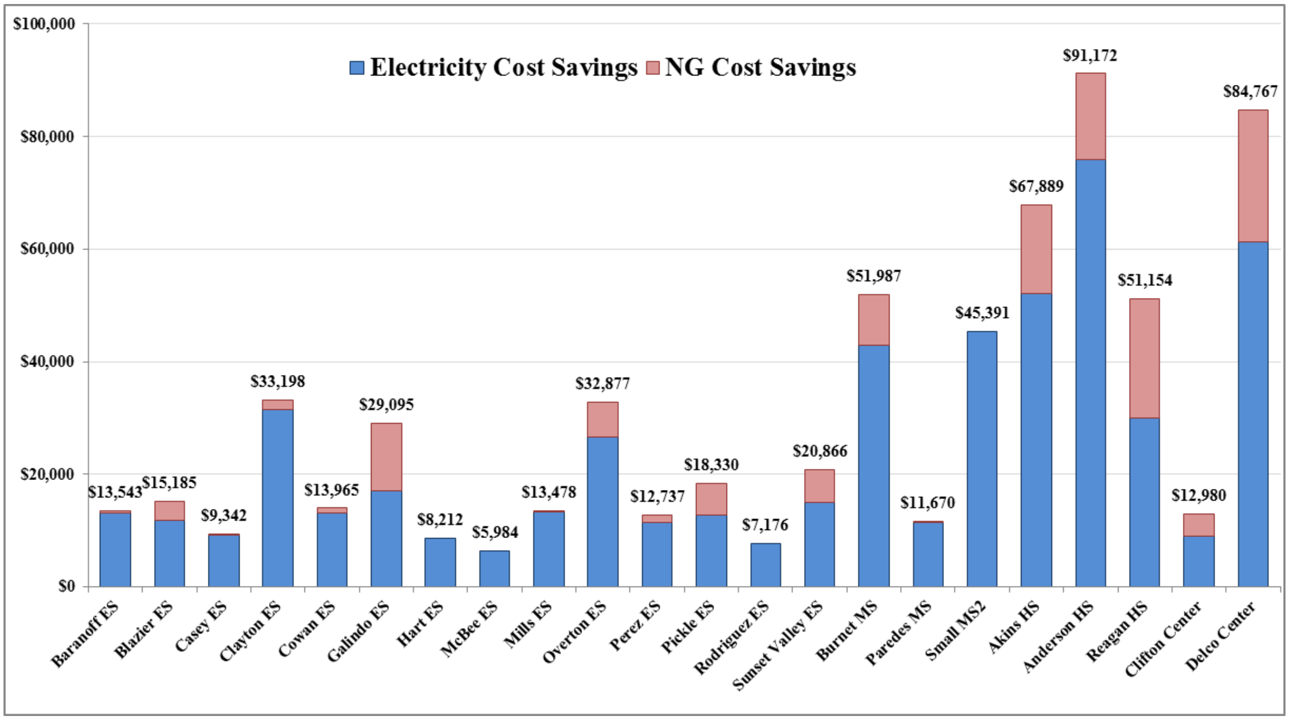
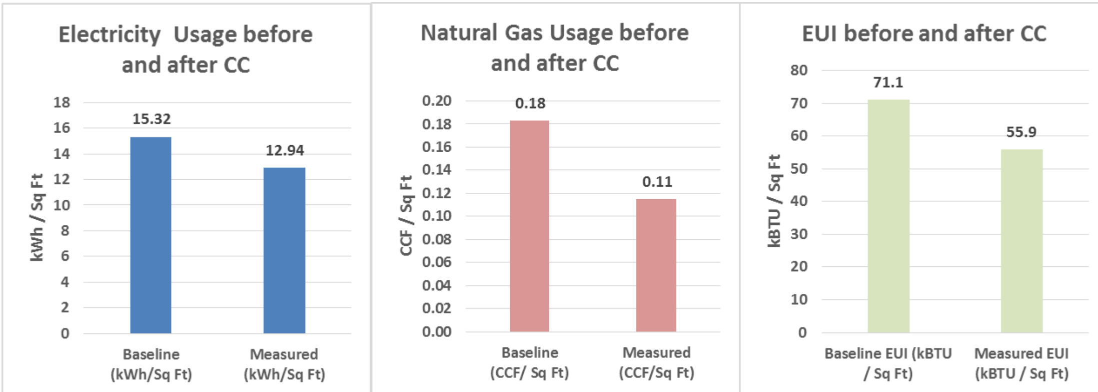


Figure 1. Total Cost Savings of CC® Facilities

Table 3. Energy Savings per Square Foot of CC® Facilities

Facilities	Gross Area (Sq. Ft)	Baseline (kWh / Sq Ft)	Measured (kWh / Sq Ft)	Savings (kWh / Sq Ft)	Baseline (CCF / Sq Ft)	Measured (CCF / Sq Ft)	Savings (CCF / Sq Ft)	Measured EUI (kBTU / Sq Ft)	Baseline EUI (kBTU / Sq Ft)	EUI Savings (kBTU / Sq Ft)
Elementary Schools										
Baranoff ES	69,322	14.3	12.3	2.0	0.01	0.00	0.01	42.2	49.9	7.7
Blazier ES	82,850	12.3	10.8	1.5	0.11	0.06	0.05	43.3	53.9	10.5
Casey ES	80,300	11.2	10.0	1.2	0.01	0.00	0.00	34.4	39.0	4.6
Clayton ES	91,960	17.4	13.7	3.7	0.08	0.06	0.02	52.5	67.5	15.0
Cowan ES	69,900	14.9	12.9	2.0	0.04	0.02	0.02	46.3	54.9	8.6
Galindo ES	78,243	17.9	15.5	2.3	0.45	0.25	0.20	79.2	107.4	28.2
Hart ES	69,610	12.6	11.3	1.3	0.00	0.01	-0.01	39.5	43.2	3.7
McBee ES	70,200	12.9	11.9	1.0	0.02	0.03	-0.01	43.7	46.1	2.5
Mills ES	69,610	14.2	12.1	2.1	0.00	0.00	0.00	41.5	48.8	7.3
Overton ES	83,365	15.4	12.0	3.4	0.17	0.08	0.10	49.0	70.6	21.6
Perez ES	78,000	19.0	17.4	1.6	0.14	0.12	0.02	71.3	78.9	7.6
Pickle ES	116,000	12.0	10.8	1.2	0.18	0.12	0.06	49.0	59.4	10.4
Rodriguez ES	69,342	13.2	12.0	1.2	0.02	0.03	-0.01	44.5	47.5	3.0
Sunset Valley ES	58,063	16.8	14.1	2.8	0.26	0.13	0.13	61.5	84.5	22.9
Middle Schools										
Burnet MS	130,797	17.6	14.0	3.5	0.39	0.30	0.09	79.1	100.2	21.1
Paredes MS	137,127	12.3	11.4	0.9	0.01	0.01	0.00	39.7	42.9	3.2
Small MS[2]	154,680	13.7	10.6	3.1	NA	NA	NA	NA	NA	NA
High Schools										
Akins HS	262,742	16.8	14.7	2.1	0.23	0.16	0.08	66.2	81.4	15.2
Anderson HS	265,180	17.3	14.2	3.1	0.23	0.15	0.07	64.1	82.2	18.1
Reagan HS	252,842	13.3	12.0	1.3	0.30	0.19	0.11	60.8	76.2	15.4
Auxilliary Service Buildings										
Clifton Center	35,198	13.8	11.0	2.7	0.63	0.49	0.14	88.1	112.3	24.2
Delco Center	35,571	40.7	22.2	18.5	1.09	0.25	0.85	101.0	251.2	150.2
Total	**2,360,902**	**15.3**	**12.9**	**2.4**	**0.18**	**0.11**	**0.07**	**55.9**	**71.1**	**15.2**



	Electricity (kWh/ Sq Ft)	Natural Gas (CCF/ Sq Ft)	EUI (kBTU / Sq Ft)
Baseline Consumption	15.32	0.18	71.1
Measured Consumption	12.94	0.11	55.9
Savings	2.4	0.07	15.2
Savings (%)	16%	37%	21%

Figure 2. Total Energy Savings per Square Foot of CC® Facilities Combined

KEY LESSONS FROM THE COMPLETED PROJECTS

Based on the CC® process implementation in the above mentioned facilities, some lessons learned are important for commissioning of facilities in the future.

RH Sensor Reliability Problems

- Humidity sensors are unreliable for the purpose of equipment operation and comfort. On multiple occasions during the site visits, it was determined that humidity sensors were either out of calibration or measuring inaccurately when compared with field measurements. Problems with humidity based control for the supply temperature and space temperature leads to unnecessary reheat.
- When RH sensors measure humidity above the setpoint, it enables the AHU, and in some cases enables the central plant, during unoccupied periods. This adds significant costs of energy as it brings the AHU into operation and the chillers and/or boilers as well.

Central Plant (CHWS and HWS) Operation During Unoccupied Periods

- CHWS and HWS operate during unoccupied periods because of constant space condition setpoints of the AHUs, FCUs, and/or VAV boxes. Having occupancy and/or setback setpoints can reduce the equipment run time, which can help reduce the energy consumption.

CHWS and HWS Loop DP Setpoints Too High

- The CHWS and HWS loop DP setpoints are set higher than necessary to meet the building demand. Higher DP leads the variable flow pumps to operate at higher speed and that leads to over-supply of chilled water or hot water. Setting up the loop DP setpoint by thoroughly investigating a building's cooling or heating requirements may help reduce the energy consumption.

HWS Operation Optimization

- Boilers operate during the summer periods due to high reheat setpoint or to maintain space temperature and RH setpoints. Disabling or manually turning off the boiler system operation during the summertime can reduce natural gas consumption as well as electricity consumption due to simultaneous cooling and heating.
- Hot water systems have high outside-air system enable setpoints. Optimizing the system enable and disable setpoints can help reduce the energy consumption by reducing the reheat and preheat at higher outside air temperatures and mitigate effect of leaky valves, high minimum airflow set points, etc.

CONCLUSIONS

Various operation and automation control problems were identified for the Air-side and Water-side systems at the facilities commissioned. The problems identified were solved using a variety of CC® measures and techniques to optimize the equipment operation and building automation control systems, which led to increased occupant comfort and reduced energy consumption. The CC® process implementation produced annual energy savings of 5,640,132 kWh and 160,688 CCF, which accounts for 16% and 37% of the baseline electricity and gas consumption. The total energy savings amount to $650,997/year (0.27 $ /sq.ft.), which is 18% of the total energy costs at an average 2012 rate calculated for 22 facilities where CC® process was implemented.

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